APS STORAGE RING OPERATION BEAM MONITORING AND ANALYSIS

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Abstract
Various software tools and applications have been developed for APS beam monitoring and analysis. These tools have been proven critical for fault identification and beam quality monitoring. A brief description of these software tools and their applications in APS storage ring beam operation analysis is presented.

1. INTRODUCTION

The Advanced Photon Source (APS)is a dedicated synchrotron radiation facility with a 7-GeV third-generation synchrotron radiation storage ring (SR)and injector that has been in operation since 1996. The injector consists of a 650-MeV electron linac, a 450-MeV accumulator ring (PAR), and a 7-GeV booster. Currently we have 23 insertion device beamlines and 21 bending magnet beamlines for user experiments. For fiscal year 2000, scheduled user beam time was 5000 hours and beam availability was 95.4%. A new operation mode, called top-up, in which the stored beam current is kept a top level by injecting repeatedly at fixed intervals, has been commissioned and is now used for user operations. APS storage ring operation parameters are listed in Table 1.

Table 1: APS Storage Ring Operation Parameters

Max. Current	102 mA	Beam Energy	7 GeV
Lifetime	>20 hours	Refill Period	12 hours
H. Emittance	7.8 nm-rad	V. Emittance	0.82 nm-rad
H. Tune	35.2	V. Tune	19.3
H. Chromaticity	4.0	V. Chromaticity	6.0
H. rms Motion	2.2 µm	V. rms Motion	1.3 µm

Beam availability, orbit reproducibility and stability, beam lifetime, and beam emittance are the most important performance parameters of APS storage ring beam operations. Continuous improvement in these areas is the main goal of the APS Operations Group.

APS storage ring has 1414 magnet power supplies, 360 beam position monitors, 16 rf cavities and 4 rf stations. Several automatic control processes perform various tasks such as slow beam orbit correction, fast orbit correction, rf frequency adjustment, etc. The storage ring has two independent interlock systems:an Access Control Interlock System (ACIS), which provides radiation safety protection and tunnel access control, and a Machine Protection System (MPS), which protects the ring components from damage by synchrotron radiation.

The control system is an EPICS-based (Experiment Physics and Industrial Control System [1]) distributed control system, which consists of workstations, local control computers (IOC), and a communications network. Machine equipment devices are represented in the IOC database as process variables (PVs). The system has a total of around 350 000 process variables. The system provides basic control and monitoring functions through its MEDM [1] control screens and alarm handlers [1].

Hundreds of MEDM screens and several alarm handlers are utilized for machine operation and maintenance. These screens and alarm handlers are used by operation crews to monitor equipment status and perform control function to individual devices.

In order to minimize user beam downtime, restoring user beam is always the first priority when beam is lost. Typically the crew spends a limited amount of time assessing the fault after a beam loss. If the fault can be cleared, the storage ring is filled and user operation continues. Detailed analysis of the fault cause is often done afterwards, and remedies for potential problems are then planned. Given the amount of information to monitor and the need to investigate events afterwards, it is obvious that the screens and alarm handlers are not sufficient. More sophisticated high-level data logging and analyzing tools are needed. As a result, many software tools have been developed for beam operation analysis. The software tools described here are part of a more general Operation Analysis Application package [2] developed at APS.

2. MONITORING AND REVIEW TOOLS

2.1 Data Logger and Review

Data loggers are general data collection processes running on workstations. They collect machine and beam data according to a set of configuration files. The configuration files define the data set and collection method. Currently the system has about 50 data categories, covering everything from beam and machine parameters to utility system status. The sampling rate for each category is set according to the rate of change of the process variables and the desired time resolution. Data files are kept for different durations from a week to more than a year, depending on their usage and the storage requirement.

Several review tools are provided for searching, filtering, sorting, plotting and printing of the logged data. Both preformatted plot settings and user-selectable plot options are supported. An orbit review tool displays the beam position data as a sequence of beam orbits around the ring, which is very useful for understanding the nature of orbit disturbances.

These logged data and review tools are particularly good for detecting slow drifts, such as slow changes of beam orbit, lifetime and emittance, temperature of ring components, vacuum pressure, etc. They are also good for finding correlations among process variables. Because of their limited time resolution, Data Logger and Review tools are not very effective for analyzing fast and nonrepeating events such as beam loss, beam orbit glitches, etc.

2.2 Alarm Logger and Review

The EPICS control system provides interfaces for monitoring the alarm status of process variables. The alarm loggers run on workstations and collect status changes of process variables according to a set of configuration files. The data contain PV name, alarm status, and timestamps. Timestamp resolution varies from tenths of a second to several seconds depending on the database configuration of the IOCs.

Currently the following subcategories are included:

- SR — storage ring magnet, beam current, rms beam motion, insertion devices
- SRF — storage ring rf cavities, klystrons, waveguides, high-voltage power supplies, etc.
- ACIS — Access Control Interlock System
- MPS — Machine Protection System
- RTFB — the fast orbit feedback system
- Timing system

The Alarm Review tool can sort, filter, search and display the logged alarms. Several display formats are provided, including a list by time and PV name, histogram by time or PV name, etc. The list by time provides a time-ordered list of the alarms in a category with alarm status information and timestamps, which is most frequently used for correlating hardware alarms with beam events.

2.3 MPS Dump Data and Review

The MPS system gets trip input from beam position monitors (BPMs), beam current monitors, rf systems, and other storage ring subsystems. It has special hardware to latch the occurrence and timestampof its input events. The timestampresolution is around 1 microsecond. The MPS dumpdata, which are saved whenever there is a beam loss, contain information associated with the beam loss, such as beam current before and after the beam loss, status and timestamp of input channels, etc.

Also included in the MPS DumpData are BPM histories, which contain turn-by-turn beam position and BPM sum readings of a selected set of BPMs. A review tool provides a list of events and timestamps and several plots showing the BPM histories.

2.4 Glitch Data Logger and Review

The Glitch Data Logger is similar to the Data Logger, except that the data acquisition is triggered by certain events. It acquires several seconds worth of data around the triggering event. The triggering event can be a beam loss, or a large orbit glitch, or a hardware event. The Glitch Data Logger has several categories, the most useful ones being beam orbit and rf system. A Glitch Data Review tool can search, select and plot the data. For orbit glitches, the review tool displays step-by-step plots of beam orbit around the storage ring. A source analysis function of the review tool analyzes the possible source corrector for each acquired orbit, which is very helpful for identifying glitches caused by magnet power supply faults. Because both the slow orbit correction and the fast orbit feedback are running, sometimes the analysis may only indicate the reaction from these systems, not the initial cause.

3. BEAM MONITORING DISPLAYS

Several real-time displays are setup on workstations in Main Control Room for beam quality monitoring. Some of them are also distributed to the beamline users through web pages.

3.1 Beam Current and Lifetime Display

This is a 24-hour stripchart showing storage ring beam current together with beam lifetime and operation mode (Fig. 1).

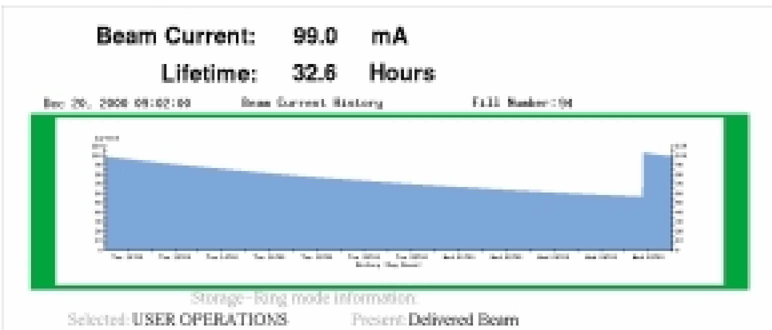

Fig. 1: Beam Current and Lifetime Display

3.2 Beam Emittance and rms Beam Motion Display

Beam profile is measured by an image processing system and a CCD camera, which receives visible light from a bending magnet beamline. Horizontal/vertical beam emittance and coupling are calculated from the profile data. The results are displayed in 24-hour stripcharts.

The rms beam motion is calculated by a DSP processor, which collects and processes data from a set of selected BPMs at a rate of upto 1600 sample/S. Figure 2 is a plot from a recent run. Most of the peaks seen on the plot are horizontal beam orbit motion generated by insertion device gap movement, which is not fully compensated.

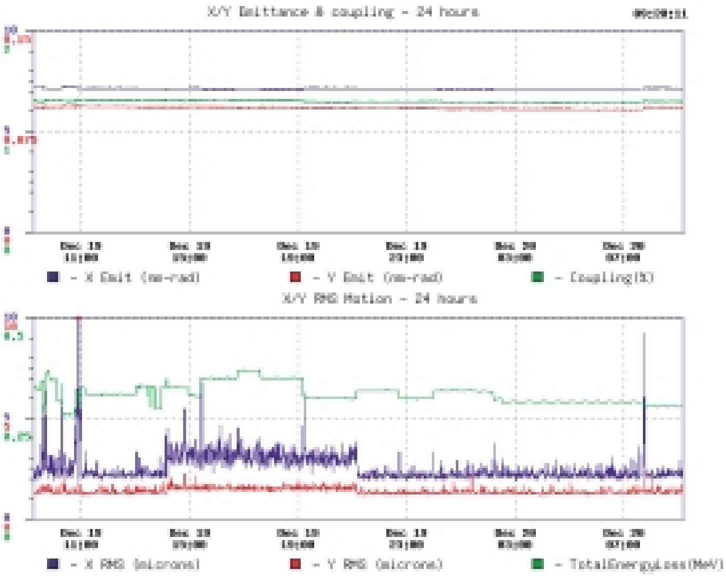

Fig. 2: Beam Emittance and rms Motion Display

3.3 Beam Orbit Display

Storage ring beam orbit is displayed with the Array Display Tool (ADT) [3], The display has three separate panels:two show the horizontal and vertical orbit errors and one provides a zoom-in view of orbit errors in both planes and the storage ring components at the selected location.

3.4 Bunch Purity Monitor

Due o the imperfect phase matching and damping of the accumulator ring, a satellite bunch with about 1% of the main bunch current exists. This satellite bunch is carried through the booster to the storage ring. Some user experiments require the satellite bunches to be small and located on the leading side of the main bunches. An Avalanche Photodiode Detector and multichannel analyzer are used to obtain bunch distribution in the storage ring. Satellite bunches as small as 1×10^{-6} of the main bunches can be resolved. The result is displayed in the Main Control Room for beam quality check.

4. BEAM LOSS AND BEAM MOTION ANALYSIS

4.1 Beam Loss Analysis

Unintended beam losses account for most of the user beam downtime. Identifying the source of beam losses helps o diagnose and eliminate faulty equipment and improve beam availability. Beam loss happens about once a day at APS. It can be causes by a tripped rf system, a glitch of a magnet power supply, a tripped interlock system, etc. If the fault is latched or the fault condition persists after the beam loss, the cause of the beam loss can be readily found. Sometimes the faulty system glitches and then returns to normal state. Furthermore, some systems, such as rf, BPM and MPS, may change or tripin reaction to a beam loss. This makes the task of finding the initial cause more difficult.

The MPS DumpData Review, with its turn-by-turn BPM histories, can provide information about orbit movement prior to the trip, the plane in which the beam orbit moves, and how fast the beam motion is, etc. From this, one can draw some partial conclusions. A slow orbit drift in one plane may indicate a corrector problem, a drift in both planes or an orbit oscillation may indicate a quadrupole problem (see Fig. 3). A fast movement of a few ms before the beam loss may indicate a fast orbit feedback corrector problem. A sudden inward movement of the horizontal beam orbit may indicate an rf problem, etc.

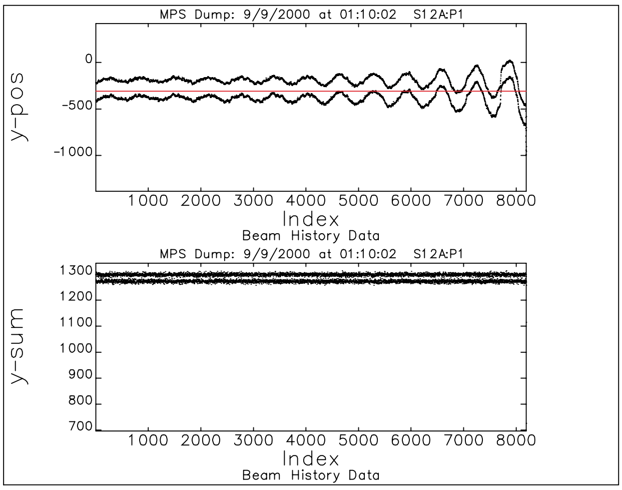

Fig. 3: BPM history of a quadrupole trip

The Glitch Data Review displays beam orbit immediately before the beam loss. The source analysis can often resolve the source location to a few magnets. Figure 4 is a plot of orbit glitch captured two seconds before the beam loss;it shows a large vertical orbit error. Figure 5 is the source analysis printout, which indicates the source is a vertical corrector around sector 33.

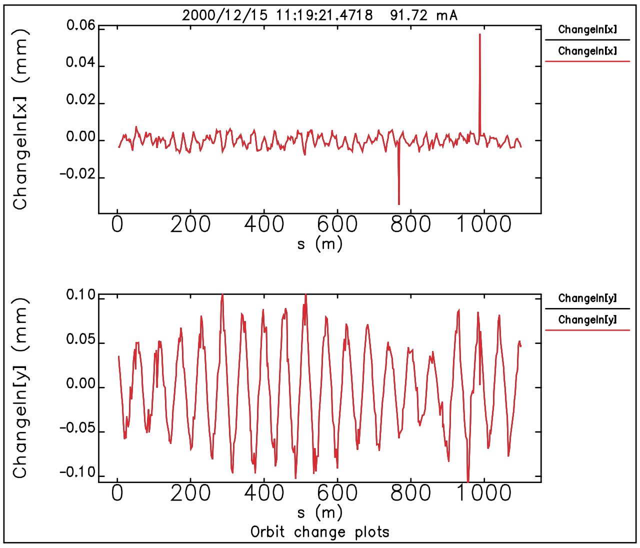

Fig. 4: Glitch Data Review output of a beam loss

Source analysis
Fri Dec 15 11:19:21 2000

Corrector	Overlap	OrbitNumber	DataTimeStamp
S33A:V3	7.598105e+01	20	2000/12/15 11:19:31.4195
S33A:V3	7.596218e+01	18	2000/12/15 11:19:29.7566
S33A:V3	7.571806e+01	14	2000/12/15 11:19:26.3473
S33A:V3	7.570471e+01	15	2000/12/15 11:19:27.1782
S33A:V3	7.570374e+01	17	2000/12/15 11:19:29.0197
S33A:V3	7.569930e+01	19	2000/12/15 11:19:30.5022
S33A:V3	7.569570e+01	16	2000/12/15 11:19:28.0323
S33A:V3	7.074574e+01	13	2000/12/15 11:19:25.2021
S33A:V3	4.918786e+01	12	2000/12/15 11:19:23.6319
S32A:V2	2.695125e+01	11	2000/12/15 11:19:22.5637
S33A:V3	9.748454e+00	10	2000/12/15 11:19:21.4718
S33A:V3	1.355786e+00	9	2000/12/15 11:19:20.4849
S3A:V1	3.455388e-01	8	2000/12/15 11:19:19.7554
S3A:V1	2.934021e-01	7	2000/12/15 11:19:19.0223
S40B:V1	2.576593e-01	6	2000/12/15 11:19:18.0184

Fig. 5: Source analysis output

If the Glitch Data Review shows an inward dispersion function like horizontal orbit, the beam loss may be caused by an rf system fault.

The Alarm Logger provides the time relation between beam loss and certain equipment alarms. If a magnet power supply alarms within a few seconds of the trip, and if the magnet is not part of the orbit correction or fast orbit feedback systems, it may be the cause of the beam loss.

Figure 6 is a partial printout of the Alarm Review for the same beam loss, in which the vertical corrector magnet S34A:V3 alarmed around the beam loss time.

SR alarms with severities major minor
2000/12/16@13.93 - 2000/12/16@15

ControlName	Severity	Status	TimeStringIOC	TimeStringWS
SRFB:xRMSmotionAlarmM	MAJOR	HIHI	2000/12/16 13:56:10.4338	2000/12/16 13:56:10.2038
SRFB:xRMSmotionAlarmM	MAJOR	HIHI	2000/12/16 13:56:57.4347	2000/12/16 13:56:57.2047
SRFB:OBL:XLoopStatusBI	MAJOR	STATE	2000/12/16 13:57:04.4350	2000/12/16 13:57:04.2153
SRFB:OBL:YLoopStatusBI	MAJOR	STATE	2000/12/16 13:57:04.4350	2000/12/16 13:57:04.2153
SR:C:cavTotalGapVolt	MINOR	LOW	2000/12/16 13:57:05.4763	2000/12/16 13:57:05.2727
S:OrbitControlLawXBC_RUN	MAJOR	SOFT	2000/12/16 07:54:49.5573	2000/12/16 13:57:05.6401
S:OrbitControlLawYBC_RUN	MAJOR	SOFT	2000/12/16 08:34:37.6829	2000/12/16 13:57:05.6710
S34A:V3:DacDiffCALC	MAJOR	HIHI	2000/12/16 13:57:06.1791	2000/12/16 13:57:06.0598
S35DCCT:CurrentLossAlarmBO	MAJOR	STATE	2000/12/16 13:57:06.5842	2000/12/16 13:57:06.3611
S35DCCT:CurrentLossAlarmLBO	MAJOR	STATE	2000/12/16 13:57:06.5842	2000/12/16 13:57:06.3611
S35DCCT:CurrentLossAlarmMBO	MAJOR	STATE	2000/12/16 13:57:06.5842	2000/12/16 13:57:06.3611
SR:C:cavTotalGapVolt	MAJOR	LOLO	2000/12/16 13:57:06.4572	2000/12/16 13:57:06.5499
S34A:V3:StatusCALC	MINOR	HIGH	2000/12/16 13:57:08.8949	2000/12/16 13:57:07.9713
SRFB:yRMSmotion30HzAlarmM	MAJOR	HIHI	2000/12/16 13:57:09.4338	2000/12/16 13:57:09.2038
SRFB:yRMSmotionAlarmM	MAJOR	HIHI	2000/12/16 13:57:09.4338	2000/12/16 13:57:09.2038

Fig. 6: Alarm Review printout

There are cases where the cause of a beam loss can not be found with all the available information. This is either due to the limited time resolution or insufficient data. For these cases, we can still use the analysis to narrow the causes down to two or three possibilities, and the results of the MPS DumpReview, the Glitch Data Review, and Alarm Review can be used as a ‘trace’ to characterize different cases for further study.

Some upgrades are planned to improve the time resolution, including a 100-Hz glitch detect software tool in the power supply controls, and a BPM movie in the fast orbit feedback system.

4.2 Beam Orbit Motion Analysis

By reviewing rms beam motion data, one can find the time, duration, and direction of beam orbit motions. For fast orbit spikes, if the orbit errors are over the trigger limit, glitch data are captured. The Glitch Data Review can be used to identify the approximate location of the source, and the Alarm Data

Review can help to narrow the source down to a particular magnet supply. For slow beam orbit motion, Data Logger review can be used to discover the character of the orbit variation and its correlation with possible noise sources.

With this approach, we are able to identify sources of most beam orbit motions, including glitching or noisy magnet power supplies, and unreliable beam position monitors in the fast orbit feedback or slow orbit correction systems.

5. CONCLUSION

The application of beam monitoring and review tools to APS beam operation analyses has helped to improve beam availability and beam quality. These tools have proved o be effective in determining causes of beam losses and excessive beam motions.

References

[1] ‘Experimental Physics and Industrial Control System’, EPICS Home page, http://www.aps.anl.gov/epics/

[2] APS Operation Analysis Group, ‘Guide to OAG Applications’, http://www.aps.anl.gov/asd/oag/oagApplications.

[3] Kenneth Evans, ‘Array Display Tool ADT Reference Manual’, http://www.aps.anl.gov/asd/oag/manuals/adt/adt.html

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